

³⁹Ar-⁴⁰Ar AGES AND TRAPPED AND COSMOGENIC NOBLE GASES IN WINONAITE METEORITES.
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Winonaites are rare primitive achondrites with chondritic-like mineralogy, whose petrology and oxygen isotopes also resemble silicates from IAB iron meteorites (1–5). Winonaites experienced varying degrees of metamorphism and partial melting at temperatures near 950°C and above (5). Winonaites do not show significant shock effects, but appear to be brecciated. Winonaites may represent IAB silicate without the metal (6), or the two types may derive from different parts of a common and distinct parent body. Because little chronological and noble gas data exist for these meteorites, we analyzed three winonaites: Winona, Mount Morris, and Pontlyfni.

³⁹Ar-⁴⁰Ar ages: The Ar-Ar ages (rectangles) and K/Ca ratios (dotted lines) for these three winonaites are given as a function of fractional release of ³⁹Ar in Fig. 1 (left). Pontlyfni shows a total age of 4.538 Ga. Thirteen temperature extractions releasing 89% of the total ³⁹Ar give a constant age of 4.531 ± 0.006 Ga. Higher ages at low extraction temperatures probably reflect some recoil loss of ³⁹Ar in the reactor, but there is little evidence that this recoil ³⁹Ar was implanted into other phases. (The 1σ age errors include all analytical uncertainties but not an ~0.5% uncertainty in the absolute age of the flux monitor.) The ³⁹Ar-⁴⁰Ar age spectrum of Winona suggests some loss of ⁴⁰Ar from a low-temperature phase with higher K/Ca, compared to Ar released at higher temperatures. The average age of 14 extractions releasing 96.5% of the ³⁹Ar is 4.42 Ga. The last ~50% of the ³⁹Ar release gives an average age of 4.45 ± 0.03 Ga, and two high temperature extractions give ages of ~4.51 Ga. Winona may have cooled slowly and remained a partially open system to Ar diffusion until ~4.4 Ga ago, which implies deep burial in the parent body. Alternatively, Winona may have experienced a thermal event <4.4 Ga ago, which caused minor loss of ⁴⁰Ar from some phases. This explanation may be consistent with surface impact brecciation. Mt. Morris shows the most complex Ar release spectrum, partly because the 775°C extraction (~35–78% ³⁹Ar release) was overheated for a short time. The first ~25% of the ³⁹Ar release from Mt. Morris indicates significant ⁴⁰Ar loss long after the meteorite formed, and could well be due to weathering of grain surfaces. The last ~2% of the ³⁹Ar release sug-

gests a recoil effect. A lower limit to the last major time of Ar degassing of Mt. Morris is probably given by the constant age of 4.40 ± 0.02 Ga shown by the five extractions releasing ~83–98% of the ³⁹Ar. This age is significantly younger than maximum ages indicated for Pontlyfni and Winona and possibly represents Ar-Ar age resetting by an impact event.

These ³⁹Ar-⁴⁰Ar ages for winonaites may be compared to Ar-Ar ages of other meteorite types. Winonaite ages show a similar range to ³⁹Ar-⁴⁰Ar ages of ~4.38–4.52 Ga that have been reported for unshocked ordinary chondrites (7). The Ar-Ar age for Pontlyfni, however, is very slightly older than the oldest dated chondrites and ages of 4.51 Ga we obtained for several acapulcoites (8), but it is similar to Ar-Ar ages of 4.53 Ga we reported for two enstatite meteorites (9). Ar-Ar and K-Ar ages reported for silicate from seven IAB irons are 4.447–4.516 Ga, with an average of 4.49 Ga (10). The younger Ar-Ar ages for all these meteorites compared to likely parent body formation times of ~4.55 Ga were likely caused by a significant period of parent body thermal metamorphism. The slightly older age for Pontlyfni compared to IAB silicate could represent a shallower depth in a common parent body. The younger ages for Winona and Mt. Morris possibly reflect impact processes.

Cosmogenic & Trapped Gases: Winona, Mt. Morris and Pontlyfni all contain significant concentrations of noble gases produced by cosmic ray interactions. The ²²Ne/²¹Ne ratios suggest relatively high shielding for Mt. Morris (1.02), and moderate shielding for Pontlyfni (1.08) and Winona (1.09). All three measured ³He/²¹Ne ratios are low (3.3–4.2), consistent either with low shielding or some He loss. If we apply the production rates for L-chondrites given by (11), which may not be strictly applicable to the composition of winonaites, we obtain ³He, ²¹Ne, and ³⁸Ar exposure ages of 20, 20, & 16 Ma for Mt. Morris, 64, 51, & 78 Ma for Pontlyfni, and 72, 31, & 58 Ma for Winona, respectively. The variation among ages calculated by the three techniques probably is due to uncertainties in sample composition and some He loss. Previous noble gas analyses of winonaites have not been reported, except for one older analysis of Winona that

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suggests somewhat larger concentrations of cosmogenic gases.

These three winonaites, especially Mt. Morris, contain significant concentrations of trapped Ar, Kr, and Xe with solar-like characteristics. They contain no trapped Ne and He. Figure 2 (lower right) compares the $^{36}\text{Ar}/^{132}\text{Xe}$ ratio versus the ^{132}Xe concentration ($10^{-10} \text{ cm}^3 \text{ STP/g}$) for the three winonaites, ordinary chondrites, C3 chondrites, ureilites, and enstatite chondrites. $^{84}\text{Kr}/^{132}\text{Xe}$ ratios for these three winonaites are 1.25-1.72. Most ordinary chondrites show $^{36}\text{Ar}/^{132}\text{Xe}$ ratios of ~40-120, and it has been argued that meteorites with ratios above ~120 contain solar-like gases in addition to a fractionated planetary-like component (12,13). These three winonaites have $^{36}\text{Ar}/^{132}\text{Xe}$ ratios of ~330-620 and contain absolute and relative concentrations of trapped noble gases that are very similar to those of several enstatite chondrites (13). Figure 3 (upper right) shows that on an isotopic ratio plot of $^{134}\text{Xe}/^{132}\text{Xe}$ versus $^{136}\text{Xe}/^{132}\text{Xe}$, Mt. Morris falls between the measured AVCC composition of carbonaceous chondrites and the solar composition. Thus, the Xe isotopic composition of Mt. Morris also suggests a solar component. Xe in Winona is almost identical

to AVCC. Pontlyfni, with the smallest measured amount of Xe and the smallest Ar/Xe ratio, plots closer to the terrestrial Xe composition. The composition labeled C1 is a planetary component derived by (14), assuming that AVCC contains solar and other Xe components. All three winonaites also contain an obvious component of ^{129}Xe from the decay of extinct ^{129}I . Measured $^{129}\text{Xe}/^{132}\text{Xe}$ ratios are 1.18, 3.87, and 2.42 for Mt. Morris, Winona, and Pontlyfni, respectively, and the concentrations of excess ^{129}Xe (units of $10^{-10} \text{ cm}^3 \text{ STP/g}$) are 1.4, 7.9, and 2.7, respectively.

References. (1) Bild, GCA 41, 1439, 1977; (2) Clayton & Mayeda, EPSL 40, 168, 1978; (3) Prinz et al., LPSC XI, 902, 1980; (4) Kimura et al., Proc. NIPR 5, 165, 1992; (5) Bendix et al., LPSC XXVI, 99, 1995; (6) Prinz et al., LPSC XIV, 616, 1983; (7) Pellas & Fiéni, LPSC XIX, 915, 1988; (8) Mittlefehldt et al. GCA 60, 867, 1996; (9) McCoy et al., GCA 59, 161, 1995; (10) Herpfer et al., GCA 58, 1353, 1994; (11) Eugster, GCA 52, 1649, 1988; (12) Mazor et al., GCA 34, 781, 1970; (13) Crabb & Anders, GCA 45, 2443, 1981; (14) Pepin, Icarus 92, 2, 1991.

